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ARMSTRONG LABORATORY

DEVELOPMENT OF A TACTILE PERCEIVED ATTITUDE TRANSDUCER

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Peter A Lurker

PETER A. LURKER, Lt Col, USAF BSC
Acting Chief
Biodynamics and Biocommunications Division

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13. ABSTRACT *(Maximum 200 words)* The objective of this effort was to design, build, and test a research device for measuring a research subject's perceived spatial orientation without the use of vision. The device consists of a multi-gimbaled structure that supports the dominant hand. A restraint system prevents slippage and shear movement. The subject indicates the perceived horizontal plane by placing his or her hand parallel to that perceived plane.

This report contains a complete description of the device as well as the results of some fundamental testing on human performance with the device. In addition, the use of the device in spatial orientation research on the Dynamic Environment Simulator, a multi-axial human centrifuge, is described.

The Tactile Perceived Attitude Transducer (TPAT) described herein is a simple and effective technique for reporting perceived attitude. Its accuracy, precision, and discrimination characteristics match those of more constrained or more complex devices.

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PREFACE

This report documents research conducted under an Independent Laboratory Innovative Research (ILIR) task, ILIRBB05, an FY90 effort. This was a $10k task that resulted in the development of a tool for use in spatial disorientation studies.

The author wishes to thank the System Research Laboratories, Inc. (SRL), who fabricated the device. Mr Steve Bolia coordinated the effort in the SRL machine shop and Mr Eric Martin performed regular calibration checks.

Also acknowledged are the valuable contributions of the branch staff, who were instrumental in this development effort. SSgt Mike Swisher developed the prototype device in the facility model shop, Lt Eric Scarboro built up the electronic interface, and Mr Robert Esken incorporated the electronic data into the data collection system.

DEVELOPMENT OF A TACTILE PERCEIVED ATTITUDE TRANSDUCER

OBJECTIVE

The objective of this effort was to design, build, and test a research device for measuring a subject's perceived spatial orientation without the use of vision. The device consists of a multi-gimbaled structure that supports the dominant hand. A restraint system prevents slippage and shear movement. The subject indicates the perceived horizontal plane by placing their hand parallel to that perceived plane.

BACKGROUND

Spatial disorientation is essentially an error between a subject's perceived orientation and their actual orientation [1]. This error may or may not be recognized by the subject [2]. There is a need for researchers to be able to determine a subject's perceived orientation without influencing that perception [3].

Ambient vision is the primary self orienting mechanism, however, a pilot is often deprived of this input while in flight (e.g. clouds, weather, darkness, cockpit distractions, or formation flying, Ref. 4). It is during these scenarios that the less dominant self-orienting mechanisms, such as tactile perception and vestibular sensation, can strongly influence the pilot's perception of orientation. Unfortunately, the vestibular system is subject to acceleration illusions [5].

The device described herein was developed to meet the need for research into the effects of multi-axis high G maneuvering on vestibular perception of orientation in the absence of ambient vision [6,7]. There have been some devices used to identify the perceived attitude of a subject while in darkness. These have been based on a single pivot point device. Correia *et. al.* provided the subject with a horizontal bar that rotated at its center to indicate perceived roll angle. However, no pitch perception was available [8]. Previous research performed on spatial disorientation demonstrators, such as the vertifuge, have attempted two dimensional measurements. Gillingham has used a device known as a "down pointer", which is a long shaft pivoted at the top of the vertifuge cockpit. This device provided the subject with a pointer he could align with his perception of down [9]. This device has been useful in clarifying the extent of the problem. However, under high G levels (>4) the device can be easily aligned with G_z by the pendulum action created by the increased weight of the subject's arm hanging on the bottom of the pointer. It is this higher level of G forces that are under investigation on the three axis human centrifuge, known as the Dynamic Environment Simulator (DES), at Wright-Patterson Air Force Base. In addition, it is possible that subjects will display a different sensitivity to a horizon, than to a vertical pole, just as pilots are accustomed to a horizontal attitude indicator, not a down pointer. The Tactile Perceived Attitude Transducer (TPAT) was designed to use the natural inclination of a person to "talk with their hands" and describe their orientation in space by moving their hand to the "level" orientation with respect to their body.

APPROACH

The device consists of an aluminum hand plate with finger restraints on a pitch axis gimbal that is anchored to a steel roll axis captured bearing. The bearing is mounted on a steel yaw axis pivot. Movement of the gimbal, pivot, and bearing are detected with potentiometers. (See Figure 1.)

An in-house mock-up and an in-house prototype were first constructed. The prototype demonstrated the feasibility of the gimbal position sensing technology. The prototype was refined to incorporate several human factors and safety features. The device was tested for repeatability and reliability. A second device was also fabricated and loaned to a spatial disorientation co-investigator at Miami University (Ohio). An AF Form 1279, Disclosure and Record of Invention, has been filed as well as an AF Form 1981, Invention Evaluation, on this device. The device has been identified by the Patents Division as Air Force Invention No. 19,661.

The use of a new attitude measurement system required not only the technical achievement of the device fabrication and installation on the DES, but also required a battery of parameter characterization and basic performance pilot studies.

Two studies were performed at the Miami University Dept of Psychology. Complete reports are attached in Appendix A. The first study was designed to quantify the accuracy and precision capability of the human-TPAT system. The second psychophysical study was designed to examine the effects of pre-trial tilting of the head and/or tilting the hand on the reported roll attitude.

Three experiments were performed by the Combined Stress Branch with the TPAT to clarify the perceptual confounds of measuring vestibular illusions on the DES. Twelve subjects were asked to report perceived location of the horizontal plane via their right hand in the TPAT while performing a head aiming task using a helmet mounted virtual display. Subjects were trained to position their heads such as to place a virtual reticule over a target disk, position their hand in the perceived horizontal plane, and pull a trigger. The task was described qualitatively as though they were flying at night while gazing at the moon, and then were required to place their hand where they believed the ground should be. Training consisted of 80 trials at one G_z with digital feedback in the viewscreen indicating a pair of zeros when the TPAT was level. Phase I placed the subject at five different roll (R) and pitch (P) attitudes (-20°R & -30°P, -5°R & -10°P, 0°R & 0°P, 10°R & 5°P, 30°R & 20°P) and two different head pitch positions (0°, 45°). Pre and post training errors were recorded. Phase II placed the torso at four different pitch angles (-30°, 0°, 30°, 45°) while maintaining the transverse plane of the head at horizontal. Phase III repeated the positions of Phase II while at 3 G_z.

RESULTS:

Detailed results of the studies conducted at Miami University are in Appendix A. A brief summary is given in the discussion section below.

Figure 2 shows example data for one subject in Phase I.

Table 1 summarizes the results of Phase I. Figure 3 represents the results of Phase II & III.

		Head at 0°			Head at 45°		
		Pre-trained	Post-trained	p value	Pre-trained	Post -trained	p value
Pitch	Mean	5.2	5.1	.9774	6.3	4.8	.6644
	St. Dev	13.4	10.2	.1033	15.1	10.1	.0229
Roll	Mean	4.9	2.4	.1437	3.7	3.8	.9746
	St Dev	12.2	9.5	.1707	12.5	8.8	.0803

Table 1. Errors in Perceived Orientation (Degrees)

DISCUSSION:

The two studies performed at Miami University, Dept of Psychology (see Appendix A for complete reports) are summarized as follows. The first study concluded that upright right-handed subjects with their eyes open could report roll attitude with a mean error between 0° and 4°. Performance with the eyes closed or with use of the non-dominant hand reduced the precision by 1°. The second experiment examined the effects of head roll and initial hand position on TPAT reported attitude. Positioning the head at a 45° roll showed a small effect on the reported attitude causing an error in the opposite roll direction, while initial hand position failed to show a significant effect on reported attitude. These two studies serve to document that the TPAT provides accuracy and precision of the same order of previously described non-visual attitude reporting systems. It also reproduces expected effects such as the E effect, where a person will err in the opposite direction of imposed head roll.

Phase I of the spatial disorientation study conducted at Armstrong Laboratory (AL) was part of a larger experiment to quantify a complex sensory illusion. The complete experiment will be described in a separate document. The data relevant to TPAT demonstration and description only are presented here. Table 1 shows three important points: 1) The magnitude of the roll accuracy agreed with that reported from Miami University. 2) Neither roll nor pitch mean errors were reduced significantly with training in either head position, although precision was significantly improved in the pitch axis. 3) Unlike the roll axis, the pitch axis appears to have a "fingers down" bias. The position that is interpreted as level, perhaps due to comfort or some muscular tension factor, is fingers slightly downward. This is most probably due to the biodynamics of the forearm in which the balanced agonist-antagonist tension of extensor/flexor system leaves the fingers downward slightly in this configuration. This bias is highly repeatable within subjects (see Figure 2).

Figure 3 shows that in the two cases where the body is prone (30°, 45°), subjects perceive an illusionary forward tilt under G. This is due to the considerable increase in force on the dorsal restraint system, even though the head was kept level in both Phase II and Phase III. The TPAT was able to discriminate this tactile illusion.

CONCLUSION

The Tactile Perceived Attitude Transducer (TPAT) described herein is a simple and effective technique for reporting perceived attitude. Its accuracy, precision, and discrimination characteristics match those of more constrained or more complex devices.

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[3] Friederici, Levelt; "Resolving Perceptual Conflicts: The Cognitive Mechanism of Spatial Orientation"; Aviation, Space, and Environmental Medicine, Sept. 1987

[4] Malcolm; "Pilot Disorientation and the Use of a Peripheral Vision Display"; Aviation, Space, and Environmental Medicine, March 1984

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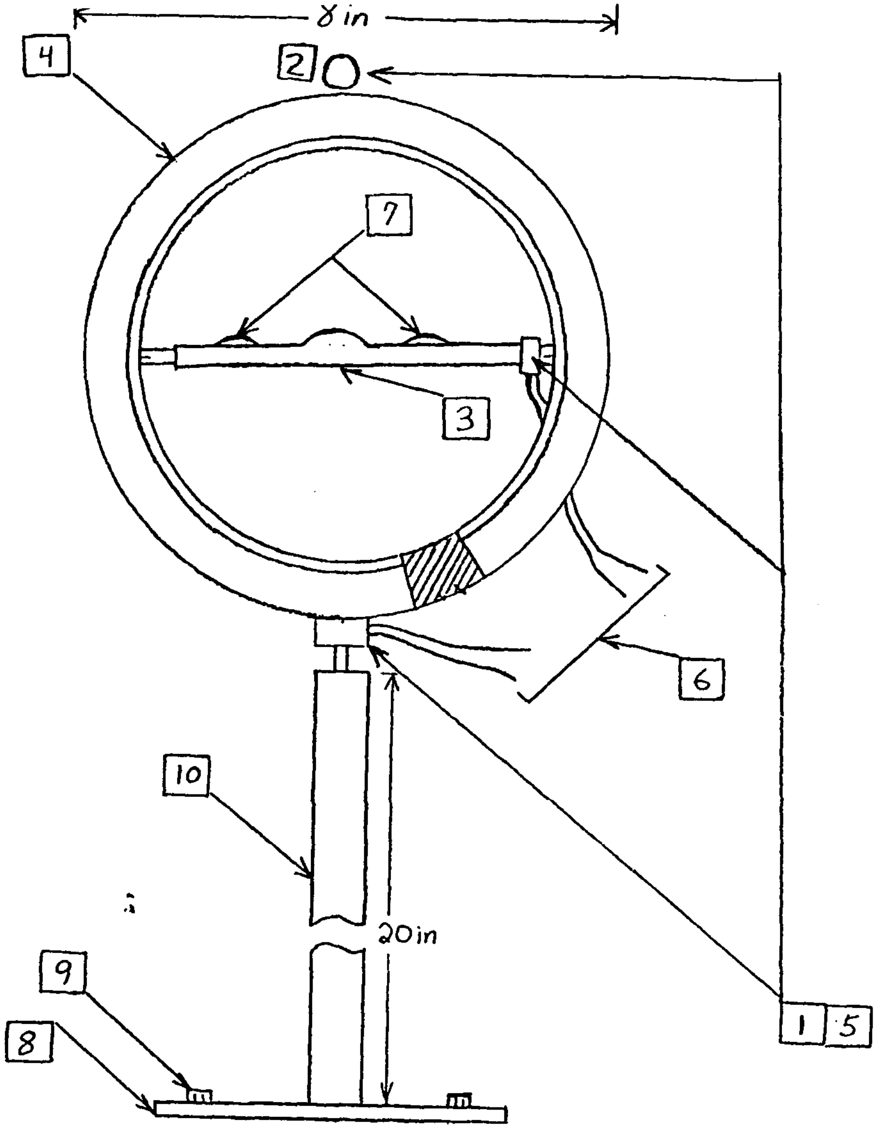
[6] Scott; "F-117 Crash Reports Cite Pilot Fatigue, Disorientation"; Aviation Week & Space Technology, May 1989

[7] Marlowe; "Spatial Disorientation and Loss of Attitude Awareness: Impact on the USAF"; 58th Annual Scientific Meeting of the Aerospace Medicine Association, May 1987

[8] Correia, Hixson, Niven; "On Predictive Equations for Subjective Judgments of Vertical and Horizon in a Force Field"; Acta Oto-Laryngologica, 1968

[9] Fulgham, Gillingham; "Inflight Assessment of Motion Sensation Thresholds and Disorienting Maneuvers"; 60th Annual Scientific Meeting of the Aerospace Medicine Association, May 1989



#	DESCRIPTION	Q
10	SQUARE STOCK, STEEL, 2 IN (FT)	2
9	BOLTS, 3/8 in	4
8	SEAT MOUNTING PLATE	1
7	NYLON WEBBING, 1 IN, (FT)	1
6	WIRE, AWG #20 (FT)	6
5	PIVOT BEARING	2
4	CAPTURE BALL BEARING	1
3	WOODEN PLATE, SHAPED	1
2	POTENTIOMETER, 10 TURN	1
1	POTENTIOMETER, 1 TURN	2

DATE : 30 APRIL 1990

DWG BY: T. L. CHELETTE

TACTILE PERCEIVED ATTITUDE TRANSDUCER 1/1

Figure 1

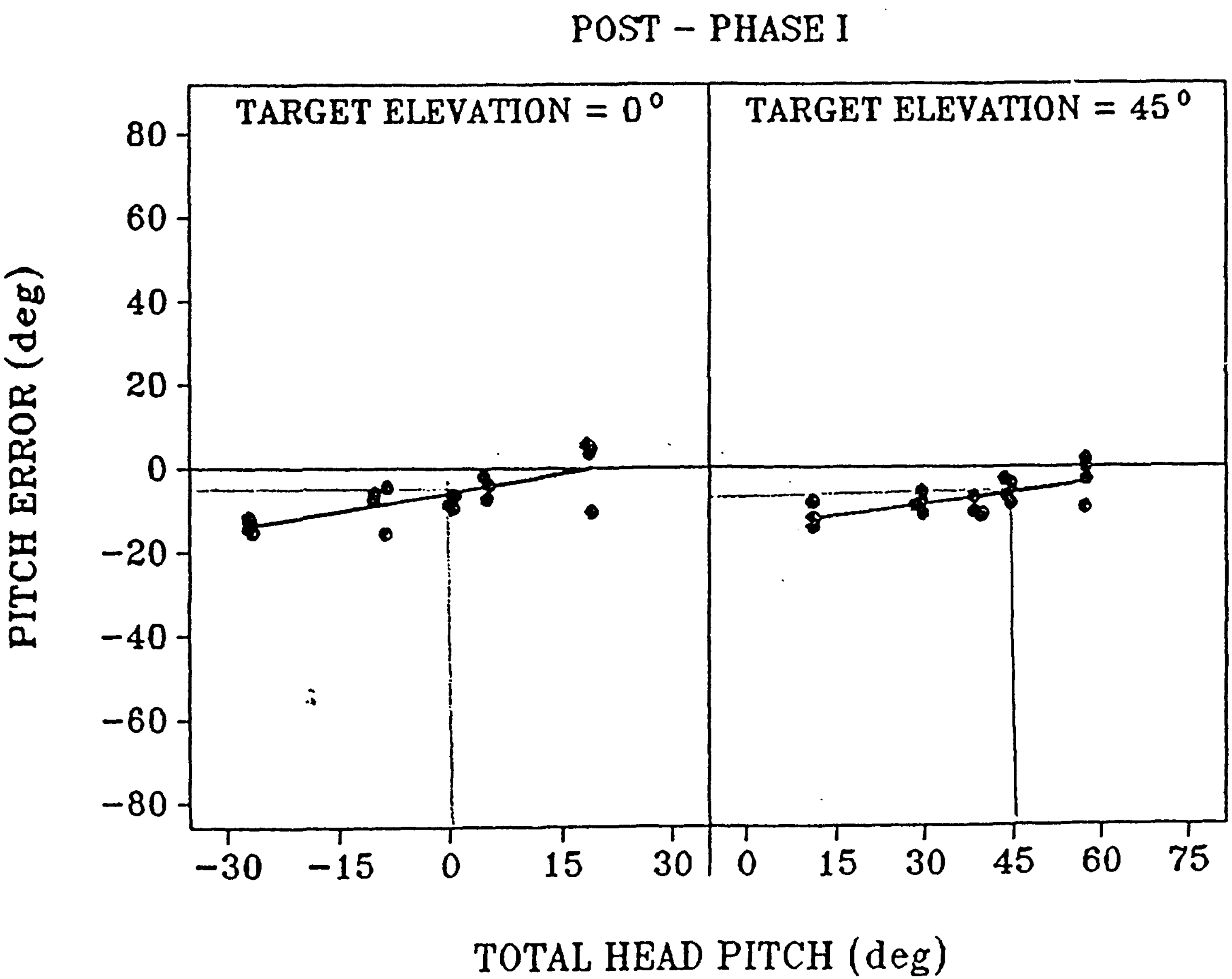

POST – PHASE I
TARGET ELEVATION = 0°
TARGET ELEVATION = 45°
PITCH ERROR (deg)
80
60
40
20
0
−20
−40
−60
−80
−30
−15
0
15
30
0
15
30
45
60
75
TOTAL HEAD PITCH (deg)

Figure 2

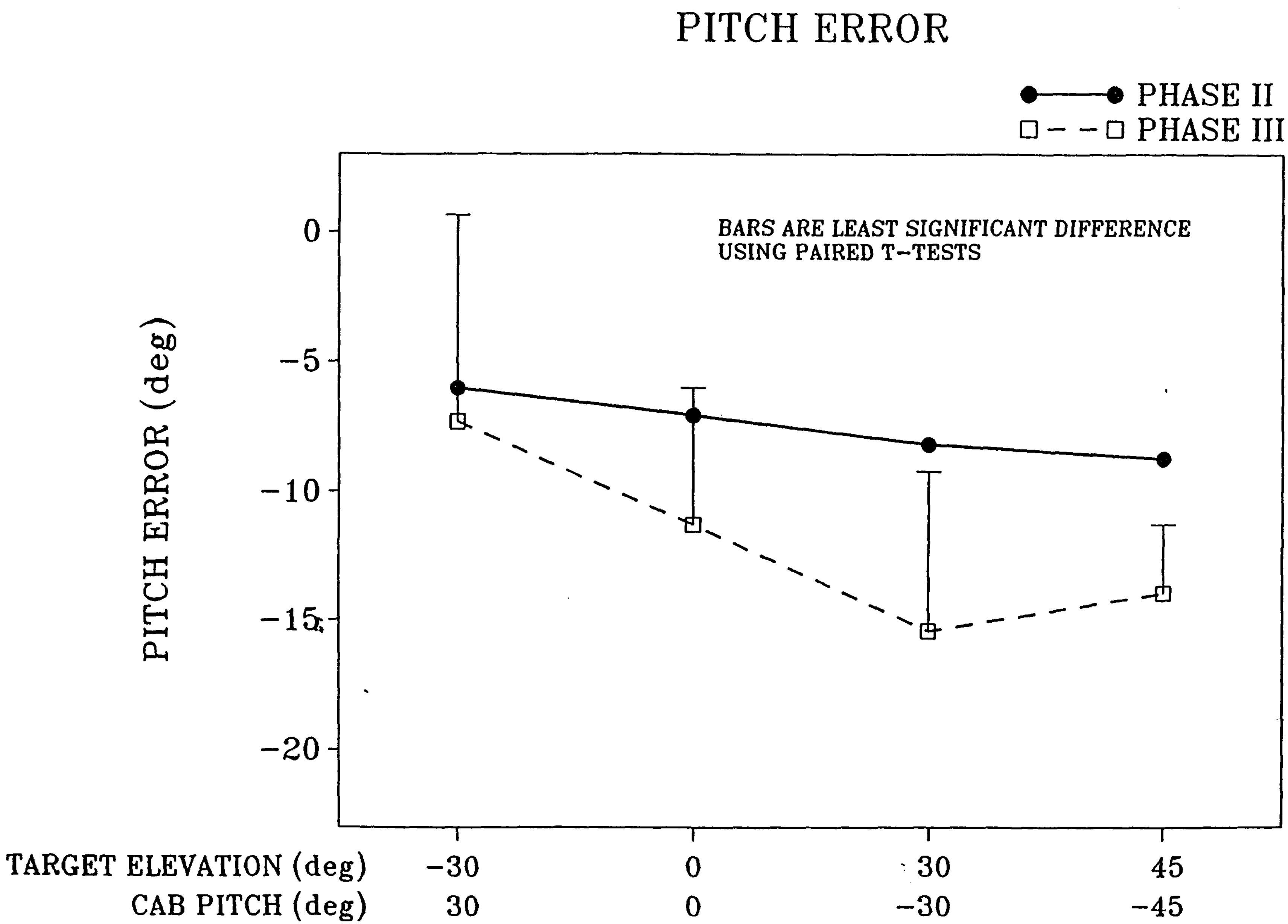

PITCH ERROR
PHASE II
PHASE III
BARS ARE LEAST SIGNIFICANT DIFFERENCE
USING PAIRED T-TESTS
PITCH ERROR (deg)
0
-5
-10
-15
-20
TARGET ELEVATION (deg) -30 0 30 45
CAB PITCH (deg) 30 0 -30 -45

Figure 3

Appendix A

TACTILE PERCEPTION OF HORIZONTAL: 1 - RESPONSE VARIABILITY

J. Pacernick, R. Futamura, D. Parker, S. Douglas and T. Carpenter-Smith

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INTRODUCTION

Previous research on tactile and visual spatial orientation has been reviewed in Howard and Templeton (1966), Howard (1982), Howard, 1986 and Clark and Horch (1986). Upright subjects either in darkness or in light are able to align a visual stimulus to either horizontal or vertical with a precision of 1 deg or less. When the subject is rolled or pitched from the upright, precision of judgement changes in a complex manner (the so-called A and E effects). Precision of tactile spatial orientation depends on several variables including the joint(s) that must be rotated, the magnitude of rotation required to align the hand or arm with horizontal or vertical, and the loading on the limbs. Previous research indicates that upright subjects either in darkness or in light are able to align their hand or arm horizontal with a precision of 2-3 deg. This precision is diminished as a function of the magnitude of joint rotation required. The effects of loading are unclear.

The purpose of Experiment 1 was to determine the precision and variability of tactile vertical using the Tactile Position and Attitude Transducer (TPAT) developed by T. Chelette at Wright-Patterson AFB.

METHOD

Subjects. Six staff members of the Miami University Spatial Orientation Laboratory staff participated in this study. All were familiar with the nature of the problem as well as general issues related to spatial orientation as a consequence of their participation in other studies. None reported a history of sensory or motor problems.

Apparatus. The TPAT apparatus has been described elsewhere. The horizontal position of the TPAT was transduced by a potentiometer excited by 5 VDC using a digital voltmeter. Calibration was achieved using a carpenter's level. The potentiometer was set so that the 0 deg (horizontal) hand position produced a reading of 2 V. Change in had orientation produced transduced signal changes of 0.0133 V per deg.

Procedure. Subjects were informed about the purpose of the experiment and were given practice trials with feedback until they reported that they felt competent to perform the task. An experimental session consisted of 80 trials during which the subject placed his/her hand in the horizontal position. Twenty trials were completed in each of four conditions: eyes open, left hand (EOL); eyes open, right hand (EOR); eyes closed, left hand (ECL); and eyes closed, right hand (ECR). Between trials, the subject's hand was moved to an off-horizontal left or off-horizontal right position in excess of 30 deg.

RESULTS

Table 1 presents the means (EOL, EOR, ECL, EOR) and standard deviations (SDEOL, SDEOR, SDECL, SDECR) for each subject calculated across the twenty trials for a given condition. These data are presented in deg; 0 deg corresponds to horizontal, and negative values are associated with a roll left off-horizontal hand position. The mean for each subject and that subject's mean standard deviation, calculated across the four conditions is labelled TOT and SDTOT respectively.

TABLE 1 (see text)

SUBJ	EOL	EOR	ECL	ECR	TOT
A	-2.9624	-2.0188	1.15038	-0.0940	-0.9812
B	1.0902	-0.1541	2.10902	0.0489	0.7735
C	0.5038	-5.6955	5.61278	-1.8910	-0.3675
D	5.4850	-2.7632	9.38346	-2.0414	2.5160
E	4.1654	0.1617	6.45865	1.5075	3.0733
F	-0.9812	-1..624	0.23308	-1.9511	-1.0404

SUBJ	SDEOL	SDEOR	SDECL	SDECR	SDTOT
A	2.20301	2.09774	1.84962	1.45113	1.90038
B	3.16541	2.84211	3.05263	3.90977	3.24248
C	2.15789	2.19549	3.31579	5.18797	3.21429
D	3.83459	2.93233	3.98496	4.32331	3.76880
E	2.38346	1.94737	3.58647	2.24060	2.53947
F	2.62406	2.69925	2.53383	2.62406	2.62030

The mean values of hand position calculated across all six subjects were as follows: EOL - 1.21679 deg; EOR - -1.98872 deg; ECL - 4.15789 deg; ECR - -0.736842 deg. The overall mean hand position across all subjects and all conditions was 0.662281 deg. Mean standard deviations for each condition across subject were: SDEOL - 2.72807 deg; SDEOR - 2.45238 deg; SDECL - 3.05388 deg; SDECR - 3.28947 deg. The mean standard deviation across all conditions and subjects was 2.88095 deg. These data are plotted in Fig. 1

DISCUSSION

The data obtained in this experiment indicate that subjects are able to report horizontal orientation using the TPAT, with or without vision, with a precision of 2-4 deg so long as they are upright. Experiment 2, which has not been completed, examines the effect of head tilt on tactile reports of horizontal. Experiment 3 will address the effects of whole body roll.

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APPENDIX A

Effects of Head Roll and Initial Hand Position on Tactile Perception of Horizontal

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ABSTRACT

Effects of head roll and initial hand position on tactile perception of horizontal were examined using the Tactile Position and Attitude Transducer (TPAT). Five subjects oriented their dominant hand to perceived horizontal while in three head roll conditions (upright, left 45 deg and right 45 deg) and with alternating initial left or right hand roll positions. The head roll conditions resulted in an E-effect (Mueller) on perception of horizontal. The effects of initial hand roll position were not statistically significant.

INTRODUCTION

As humans we need to know about our spatial orientation with respect to our environment. This is accomplished through a cooperative effort of several sensory systems including the visual, auditory, somatosensory, and vestibular systems (Parker et al., 1979). This study addressed the somatosensory and vestibular systems and interactions between them.

The somatosensory system includes the kinesthetic and cutaneous sensory systems. The kinesthetic sensory system processes information regarding motion and static spatial orientation resulting from mechanical stimulation of the muscles, tendons, and joints while the cutaneous sensory system processes sensory inputs from skin receptors. It is from both of these types of receptors that information regarding body and limb orientation is obtained (Schiffman, 1990). In this study, the orientation of the head, neck, torso, arm, wrist and hand, with respect to each other, are clearly of interest.

The vestibular system consists of the semi-circular canals and the otolith organs. The semi-circular canals are three fluid-filled sacs that detect angular accelerations in each of the three major planes of the body. The otolith organs, comprised of the utricles and saccules, detect linear acceleration along the three planes of the body, and also detect head orientation with respect to gravity (Schiffman, 1990). It is this detection of posture by the otoliths, whether upright or at some angle, that is crucial to this study of the effect of head tilt.

Mueller (1916) discovered that for most people, small rolls of the head cause a truly vertical line to appear tilted in the same direction as the head; i.e., that head roll produces a tilt of the apparent vertical in the opposite direction of the head tilt. This-so called E-effect reaches a maximum value of between 3 and 12 deg at head tilts of between 30 and 40 deg (Bauermeister, 1964; Miller et al., 1965; Wade, 1969).

Previous research on tactile perception of horizontal by Pacernick et al. (1991) showed that subjects were able to report horizontal orientation, with or without visual cues, with a precision of 2-4 deg while in an upright position. Their study also showed the effectiveness of the TPAT device to assess a subject's ability to reorient hand roll position to perceived tactile horizontal.

The present study was designed to address the following question: do head roll and initial hand roll position affect tactile perception of horizontal? We hypothesized that most subjects would exhibit an E-effect, i.e., overcompensation due to head tilt, as observed in previous studies using vision.

METHOD

Subjects. Five subjects, three men and two women, from the Miami University Spatial Orientation Laboratory staff participated in this study. All subjects were familiar with the device and the nature of the experiment as a consequence of their participation in other studies. None of the subjects reported a history of sensory or motor problems. All subjects were right-hand dominant and were tested using their right hands.

Materials. The apparatus in this experiment was the Tactile Position and Attitude Transducer (TPAT) developed by T. Chelette at Wright-Patterson Air Force Base, Dayton, Ohio. The horizontal roll position of the TPAT was transduced by a potentiometer excited by 5 vDC using a digital voltmeter. Calibration was obtained using a carpenter's level. The potentiometer was set so that the 0 deg (horizontal) hand position produced a reading of 2.0v. The potentiometer was also recalibrated after every 5 trials. Change in hand orientation produced changes of 0.0133 v/deg. Head tilt position was obtained using a head frame.

Procedure. Subjects were informed about the purpose of the experiment and were given practice trials with visual feedback until they reported that they felt competent enough to perform the task. Subjects were not informed about the specific hypotheses of this study. The experiment consisted of three sessions (days) of 60 trials each during which subjects were asked to reorient their hands to horizontal with their eyes closed. Ten trials were performed in each of the six conditions -- three head positions (upright, 45 deg left roll and 45 deg right) crossed with two initial hand roll positions (left - counter-clockwise or right - clockwise). Between trials, the subject's hand was rotated alternately to off-horizontal left or off-horizontal right roll positions greater than 30 deg. Subjects were required to keep their hands in the initial off-horizontal position at least three sec before attempting to reorient to horizontal. The three sessions were separated by at least 24 hours each to prevent subject fatigue, and within subject counterbalancing for head position order was achieved using a Latin square design.

RESULTS

Mean hand position values, for the three head conditions and the two hand conditions were as follows:

HEAD	HAND	N	MEAN
L	LT	15	1.56 deg
L	RT	15	4.27 deg
R	LT	15	-8.86 deg
R	RT	15	-4.88 deg
U	LT	15	-5.12 deg
U	RT	15	-2.78 deg

where 0 deg is horizontal, positive values indicate left (counter clockwise) and roll and negative values indicate right (clockwise) hand roll.

Collapsed across the hand conditions, means for the head positions were as follows:

GROUPING *		MEAN	N	HEAD
	A	2.92 deg	30	L
	A			
B	A	-3.95 deg	30	U
B				
B		-6.87 deg	30	R

* Means with the same letter are not significantly different.

Collapsed across head positions, means for the initial hand positions were as follows:

GROUPING*	MEAN	N	HAND
A	-1.13 deg	45	RT
A	-4.14 deg	45	LT

* Means with the same letter are not significantly different.

A three (days) by three (head positions) by two (initial hand positions) within-subjects analyses of variance was calculated with the following results. There was a significant effect of head roll [$F(2, 8) = 7.54$, $p < 0.01$]. The effect of initial hand position was not significant [$F(1, 4) = 7.42$, $p = 0.0528$]. The head by hand interaction did not approach significance [$F(2, 8) = 0.59$, $p = 0.58$]. A complete printout for the ANOVA is presented in Appendix A.

DISCUSSION

The effects of head tilt on tactile perception of horizontal were similar to those seen in experiments employing a visual dependent variable and support an E-effect. When subjects rolled their head left, they perceived their horizontal hand as rolled toward the right. To compensate for this illusion, they rolled their hand left when they reported tactile horizontal. This same phenomenon is reported in experiments where the dependent variable is perceived visual vertical. These observations support the view that the TPAT provides information that is analogous to that obtained using judgements of perceived visual vertical. Of course, the main advantage of the TPAT is that it permits judgements for pitch, roll and yaw simultaneously.

The direction of initial hand roll had a nearly significant effect on the direction of tactile horizontal. If this effect were confirmed in other experiments it could be understood in terms of the well-known visual tilt aftereffect, which is hypothesized to result from an opponent processes mechanism (Howard, 1982).

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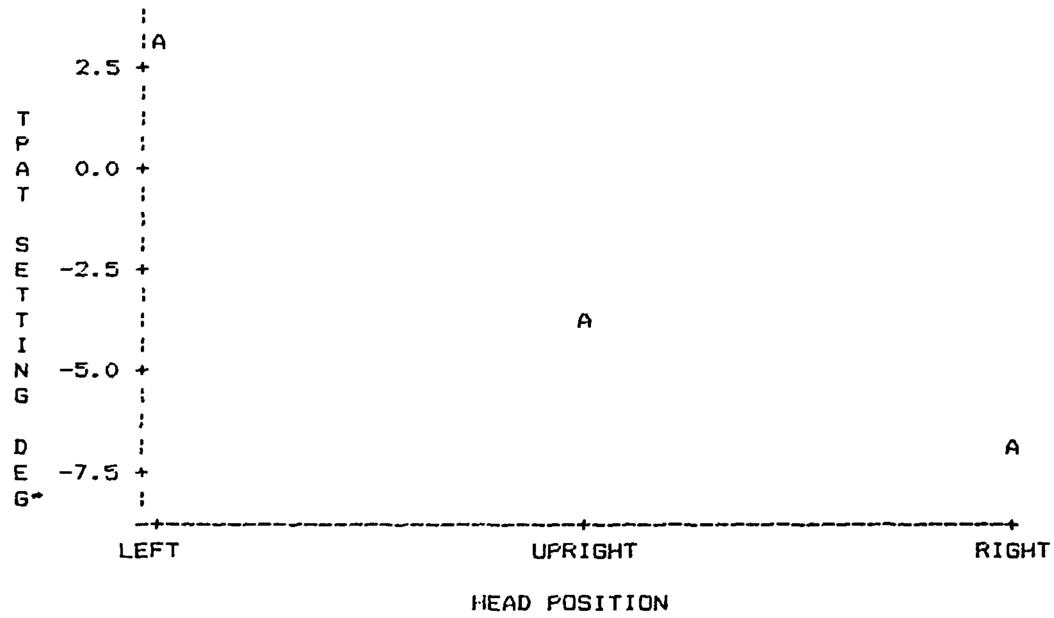
FIGURE 1 EFFECT OF HEAD POSITION ON PERCEPTION OF HORIZONTAL



*Positive TPAT setting indicate left roll.

APPENDIX A

ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJ	5	BL JP JS SD TS
DAY	3	1 2 3
HEAD	3	L R U
HAND	2	LT RT

NUMBER OF OBSERVATIONS IN DATA SET = 90

DEPENDENT VARIABLE: DV

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	89	5094.67976269	57.24359284
ERROR	0	0.00000000	0.00000000
CORRECTED TOTAL	89	5094.67976269	

MODEL F = .　　　PR > F = .

R-SQUARE	C.V.	ROOT MSE	DV MEAN
1.000000	0.0000	0.00000000	-2.63567251

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUBJ	4	1168.24326103	.	.
DAY	2	318.68509369	.	.
SUBJ*DAY	8	362.30722420	.	.
HEAD	2	1518.07607113	.	.
SUBJ*HEAD	8	805.63222844	.	.
DAY*HEAD	4	6.71198925	.	.
SUBJ*DAY*HEAD	16	266.92770523	.	.
HAND	1	203.53892312	.	.
SUBJ*HAND	4	109.73081450	.	.
DAY*HAND	2	19.95277417	.	.
SUBJ*DAY*HAND	8	53.79451385	.	.
HEAD*HAND	2	11.14594129	.	.
SUBJ*HEAD*HAND	8	75.95373145	.	.
DAY*HEAD*HAND	4	23.48210250	.	.
SUBJ*DAY*HEAD*HAND	16	150.49738884	.	.

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJ*DAY AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
DAY	2	318.68509369	3.52	0.0801

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJ*HEAD AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
HEAD	2	1518.07607113	7.54	0.0144

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJ*HAND AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
HAND	1	203.53892312	7.42	0.0528

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJ*DAY*HEAD
AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
DAY*HEAD	4	6.71198925	0.10	0.9807

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJ*DAY*HAND
AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
DAY*HAND	2	19.95277417	1.48	0.2831

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJ*HEAD*HAND
AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
HEAD*HAND	2	11.14594129	0.59	0.5783

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: DV
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ
ALPHA=0.05 DF=8 MSE=45.2884
CRITICAL VALUE OF STUDENTIZED RANGE=4.041
MINIMUM SIGNIFICANT DIFFERENCE=4.9651
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	DAY
	A	-0.245	30	1
	A			
	A	-2.818	30	2
	A			
	A	-4.844	30	3

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: DV
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ
ALPHA=0.05 DF=8 MSE=100.704
CRITICAL VALUE OF STUDENTIZED RANGE=4.041
MINIMUM SIGNIFICANT DIFFERENCE=7.4038
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	HEAD
	A	2.923	30	L
	A			
B	A	-3.956	30	U
B				
B		-6.874	30	R